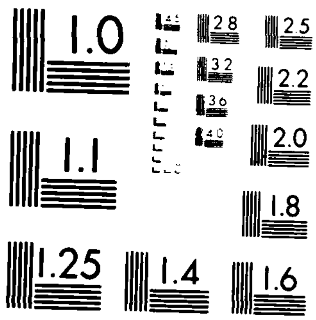
AD-A122 832 THE SOLAR RADIATION FIELD AT TWILIGHT BELOW 100 KM: A SPHERICAL MODEL(U) NAVAL RESEARCH LAB WASHINGTON DC E O HULBURT CENTER FOR SPACE.. D E ANDERSON MAY 82 1/1

UNCLASSIFIED FAA/EE-82-18 DTFA01-81-Y-10512 F/G 3/2 NL

END
DATE
FILMED
[illegible]
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

17

Report No. FAA-EE-82-18

U.S. Department of Transportation
Federal Aviation Administration

The Solar Radiation Field at Twilight Below 100 KM: A Spherical Model

Office of Environment
and Energy
Washington, DC 20591

Donald E. Anderson, Jr. May 1982

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-EE-82-18	AD A122 832	

4. Title and Subtitle	5. Report Date
The Solar Radiation Field at Twilight below 100 Km: A Spherical Model	May 1982
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Donald E. Anderson, Jr.	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Naval Research Laboratory 4555 Overlook Avenue, S.W. Washington, D.C. 20375	11. Contract or Grant No. DTFA01-81-Y-10512
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Office of Environment and Energy Air Quality Division Washington, D.C. 20591	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Time dependent calculations of minor species distributions require as input the solar radiation field as a function of altitude and solar zenith angle. An isotropic spherical model of the radiation field has been developed to determine the solar radiation field in twilight. Comparison of the spherical model with a plane parallel model of the multiple scattering of radiation at twilight shows that: (1) for solar zenith angles less than 95^{o}, plane parallel solutions are suitable if the initial deposition of solar energy is calculated for a spherical atmosphere; (2) for solar zenith angles greater than 95^{o}, the plane parallel radiation field is several orders of magnitude smaller than that calculated with the spherical model; (3) at altitudes above 40 km, the spherical model predicts 10 - 20 % less radiation than the radiation field calculated with the plane parallel model.

17. Key Words	18. Distribution Statement
Troposphere, Stratosphere, Solar Radiation, Twilight, Multiple Scattering	This document is available to the public through the National Technical Information Service Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	17	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

THE SOLAR RADIATION FIELD AT TWILIGHT

BELOW 100 KM: A SPHERICAL MODEL

by

Donald E. Anderson, Jr.
E. O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, DC 20375

Abstract

Time dependent calculations of minor species distributions require as input the solar radiation field as a function of altitude and solar zenith angle. An isotropic spherical model of the radiation field has been developed to determine the solar radiation field in twilight. Comparison of the spherical model with a plane parallel model of the multiple scattering of radiation at twilight shows that: (1) for solar zenith angles less than 95°, plane parallel solutions are suitable if the initial deposition of solar energy is calculated for a spherical atmosphere; (2) for solar zenith angles greater than 95°, the plane parallel radiation field is several orders of magnitude smaller than that calculated with the spherical model; (3) at altitudes above 40 km, the spherical model predicts 10 - 20 % less radiation than the radiation field calculated with the plane parallel model.

CONTENTS

LIST OF FIGURES

I. Introduction

Time dependent calculations of minor species distributions require as input the solar radiation field as a function of altitude z and solar zenith angle Θ_o. There has been some concern that results from plane parallel models may be incorrect at twilight. In the present study, an isotropic spherical model of the radiation field has been developed to address the twilight problem. The model does not include refraction effects, ground albedo, or aerosols, but does include molecular oxygen (O_2) and ozone (O_3) absorption, and multiple scattering in an inhomogeneous, spherical atmosphere. Ground albedo is relatively unimportant in twilight; refraction effects may be neglected except when making comparison to high resolution measurements; and the presence of aerosols slightly enhance the degree of multiple scattering at all wavelengths. These effects may be included at a later time but the basic results described here will not be affected.

II. The Models

The model atmosphere employed is the U.S. Standard Atmosphere (1976) with the O_3 profile from Nicolet (1978). The O_3 cross section between 200 and 800 nm is also from Nicolet (1978), as is the O_2 absorption cross section. The model atmosphere is shown in Figure 1 and the O_3 and O_2 cross sections in Figure 2.

The spherical radiative transfer model is patterned after the model developed by Anderson and Hord (1977) for calculation of resonance scattering by atomic hydrogen of the solar Lyman-alpha flux incident on planetary thermospheres and exospheres. The basic physical model for Rayleigh and Mie scattering is described for the plane parallel case by

Anderson and Meier (1979) and Meier et al., (1982). Detailed numerical results for the wavelength region 200-800 nm in the troposphere and stratosphere are described by Nicolet et al., (1982).

Briefly, both the plane parallel and spherical theory used in this study solve the integral equation of radiative transfer for the flux into a volume element F. F is normalized to the solar flux at the top of the atmosphere F_∞, where F_∞ is in units photons $cm^{-2}s^{-1}nm^{-1}$. The plane parallel model assumes azimuthal symmetry and utilizes Chandrasekhar's (1960) E functions to reduce the problem to one dimension: namely F as function of vertical optical depth τ, or altitude. In the spherical code, azimuthal symmetry is assumed, but F is now an interlocking function of τ and Θ_o. Thus, on multiple scattering, photons are allowed to migrate in both τ and Θ_o. It will be shown below that the effects of this coupling can be very large in twilight.

III. Results

A. Calculation of F_o

When plane parallel models are employed to calculate $F(\tau, \Theta_o)$, the attenuated direct flux $F_o(\tau, \Theta_o)$ is usually given by

$$F_o(\tau, \Theta_o) = \exp[-(\tau + \tau_p) \sec \Theta_o] \tag{1}$$

τ is related in a straightforward way to z noting that

$$\tau = \sigma_s \int N(z)dz \tag{2}$$

where σ_s is the cross section for Rayleigh scattering, and N is the neutral atmosphere density at altitude z in the atmosphere. An absorption which removes a photon from further scattering is designated a pure absorption, and the pure absorption optical depth is

$$\tau_p = \int [\sigma_{O_3} N_{O_3}(z) + \sigma_{O_2} N_{O_2}(z)]dz \tag{3}$$

where the σ's are the pure absorption cross sections. If the pure absorber is homogeneously mixed with the scatters, then Chapman functions (Smith and Smith, 1972) may be used in place of sec Θ_o in (1) to account for effects on F_o of sphericity. Since O_3 is not homogeneously mixed neither Chapman functions, nor sec Θ_o is appropriate. Instead, the true slant optical depth must be calculated taking into account the inhomogenities due to ozone. A comparison of (1) with the correct F_o is shown in Figure 3 at Θ_o = 80, 86, and 88^o, for λ = 325 nm, τ_p = 0.14 and λ = 325 nm, τ_p = 0, respectively. Clearly, below 50 km, spherical effects are important for $\Theta_o > 80^o$. No comparisons are made for $\Theta_o \geq 90$, since the plane parallel F_o is not defined. In Figure 4, F_o is shown for λ = 325 nm and Θ_o from 0^o to 98^o. The wavelength λ = 325 nm is chosen throughout for illustrative purposes, since both pure absorption and multiple scattering effects are important. However, the model does cover the entire range 200 - 800 nm.

B. Calculation of F

Values of F at λ = 325 nm are shown in Figure 5 for Θ_o = 60^o to 104^o. The dashed curves are the values of F calculated with the correct spherical F_o, but the multiple scattering is assumed to take place in a plane parallel atmosphere. It is clear from Figure 5 that for $\Theta_o < 92^o$ the plane parallel solution with a spherical F_o is adequate to describe the multiple scattering. However, for $\Theta_o > 96^o$ the plane parallel solutions are orders of magnitude lower than the spherical solutions and are off scale.

Another result, not apparent on the log plot in Figure 5, is that above 40 km, F (spherical) falls about 10 to 20% below F (plane parallel) at all Θ_o. This result has been noted before (Strickland and Anderson,

1973) and occurs because a photon emitted at a given altitude in a spherical atmosphere has a greater probability of escape from the medium than in a plane parallel atmosphere. As $z \rightarrow \infty$ the escape probability approaches 0.5 in a plane parallel medium, and 1.0 in a spherical medium.

As an example of the wavelength dependence, Figures 6 and 7 show $F(\Theta_o)$ for λ = 250 and 450 nm, respectively. At short wavelengths (λ < 325 nm) ozone absorbs much of the radiation so that F is low, and is essentially zero below the ozone maximum. As λ increases beyond 350 nm F gradually decreases in proportion to the Rayleigh optical depth, and thus the multiple scattering decreases.

IV. Discussion

The purpose of this research effort was: (1) to develop a spherical model of the multiple scattering of solar radiation in the twilight atmosphere; and (2) to establish a range of validity for the use of plane parallel models in twilight. The initial model has been developed. A more sophisticated model may be developed in the future which includes such effects as refraction of sunlight, anistropic scattering by aerosols, ground albedo, and clouds. But the result of comparison with the present model and a plane parallel model suggests that for $\Theta_o < 95^o$, the plane parallel solution is sufficient, if the proper F_o is used. This conclusion is stated with the caveat that the spherical solutions are 10-20% lower than the plane parallel solutions at all Θ_o for z > 40 km.

For $\Theta_o > 95^o$ plane parallel solutions are not satisfactory, and the future improvement of the present model depends to some extent on whether or not the enormous differences in F between the two models have any effect on the photochemistry in the atmosphere below 100 km.

BIBLIOGRAPHY

Anderson, D. E. Jr., and C. W. Hord, "Multidimensional Radiative Transfer: Applications to Planetary Coronae", Planet. Space Sci., 25, 1977.

Anderson, D. E. Jr., and R. R. Meier, "The Effects of Anisotropic Multiple Scattering on Solar Radiation in the Troposphere and Stratosphere", Appl. Optics, 18, 1955.

Chandrasekhar, S. "Radiative Transfer", Dover Publications, Inc. New York, New York, 1960.

Meier, R. R., D. E. Anderson, Jr., and M. Nicolet, "Radiation Field in the Troposphere and Stratosphere: I. General Analysis", Planet. Space Sci., in press, 1982.

Nicolet, M., "Etude des reactions chimiques de l'ozone dans la stratosphere", Institut Royal Meteorologique de Belgique, Brussels, Belgium, 1978.

Nicolet, M., R. R. Meier, and D. E. Anderson, Jr., "Radiation Field in the Troposphere and Stratosphere: II. Numerical Analysis", Planet. Space Sci., in press, 1982.

Smith, F. L. III., and C. Smith, "Numerical Evaluation of Chapman's Grazing Incidence ch(X,χ), J. Geophys. Res., 77, 3592, 1972.

Strickland, D. J., and D. E. Anderson, Jr., "Theoretical Emergent Lyman-α Intensities From Mars", J. Geophys. Res., 78, 1973.

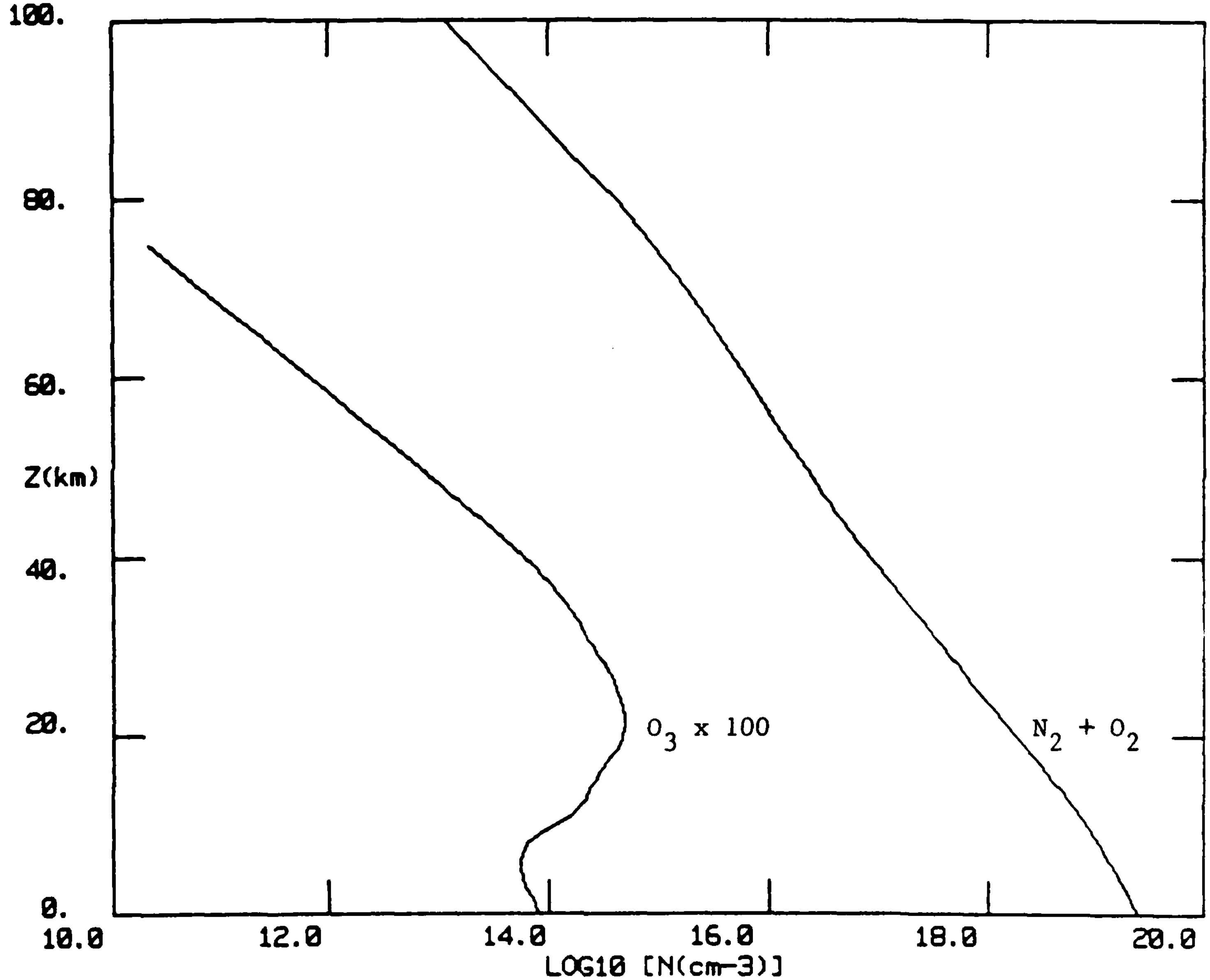


Figure 1. Neutral Atmosphere Density Distribution. Ozone is scaled by a factor of 100.

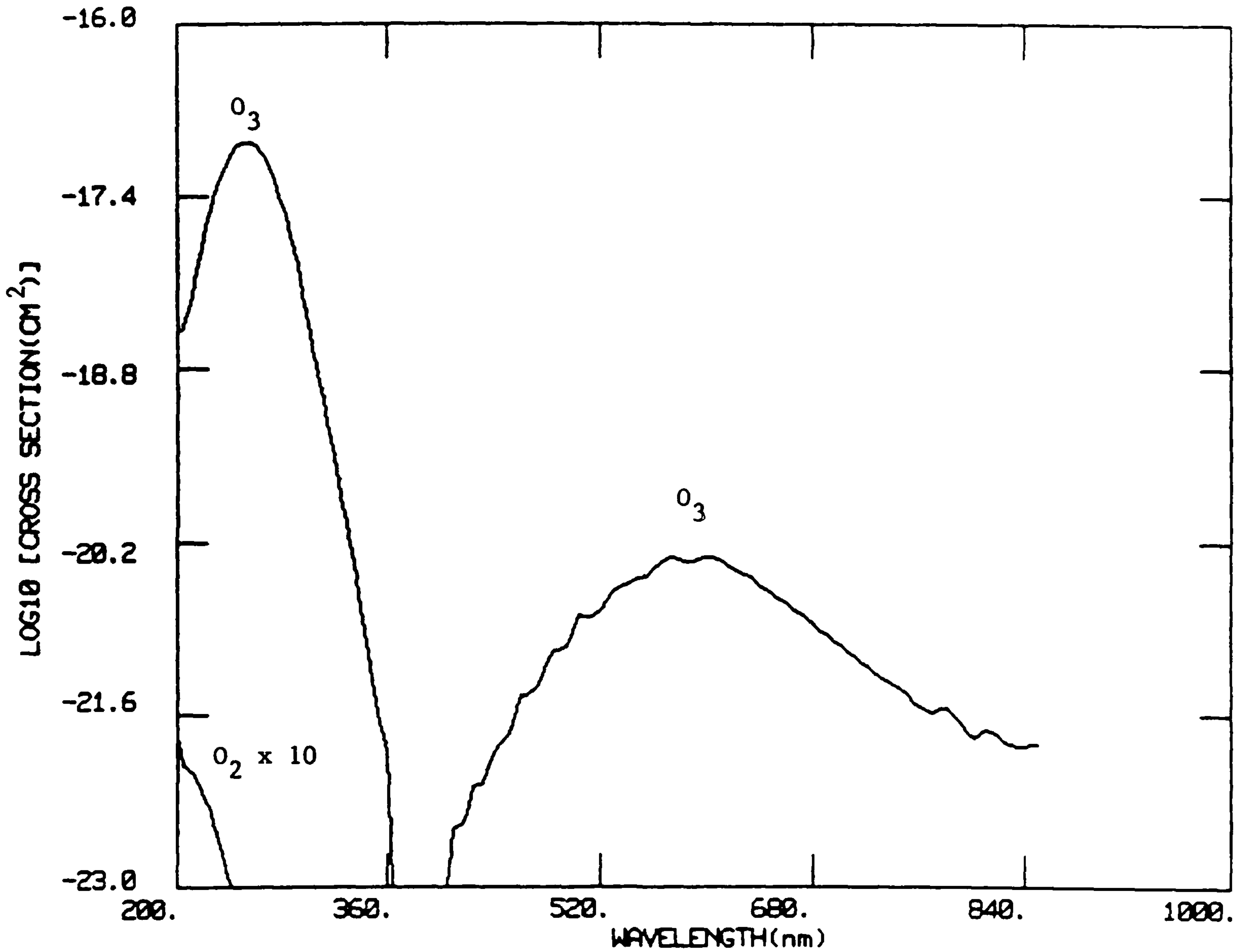


Figure 2. O_2 and O_3 pure absorption cross sections. O_2 cross section is scaled upward by a factor of 10.

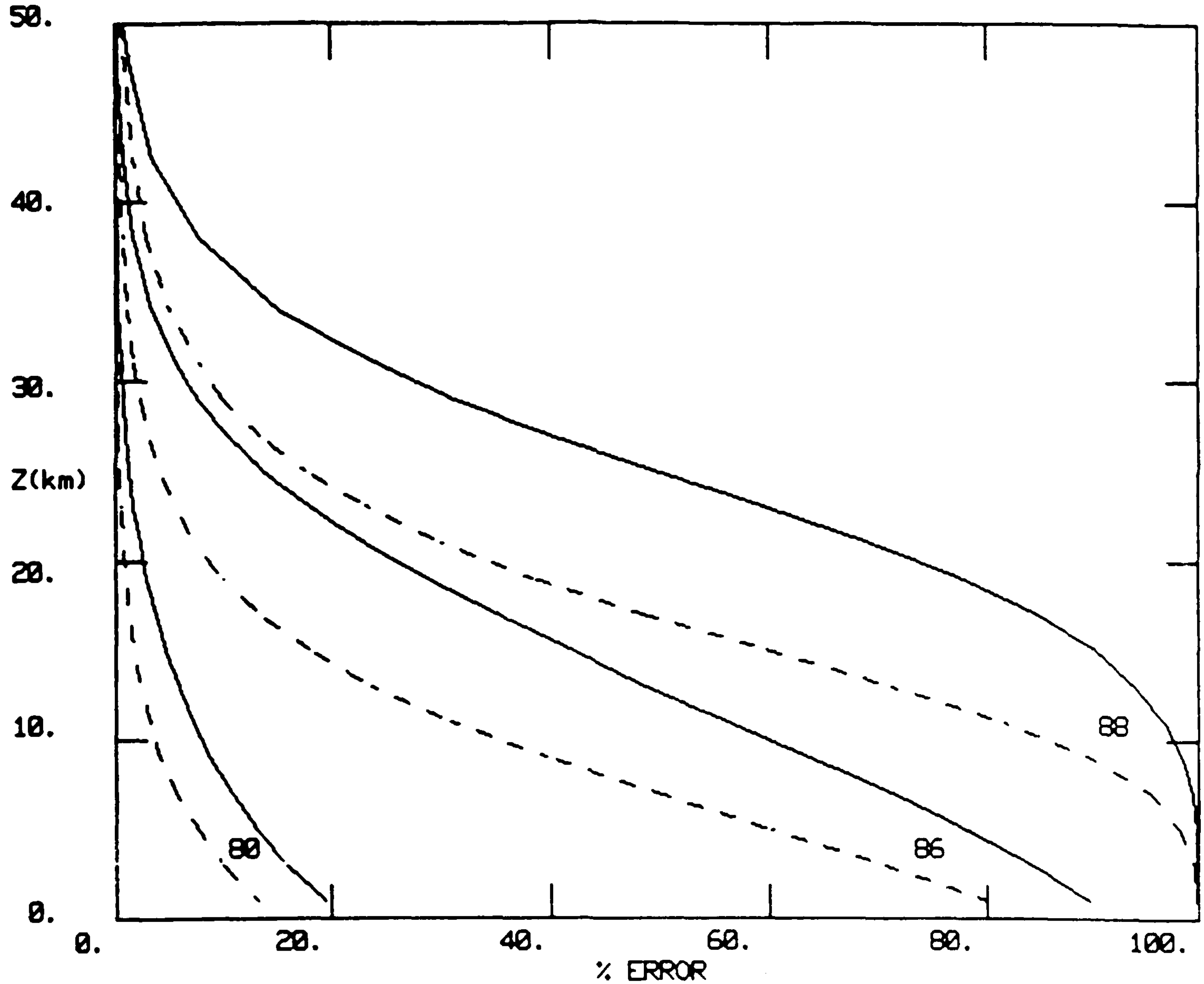


Figure 3. Percent error in plane parallel F_o when compared to spherical F_o at λ = 325 nm and θ_o as indicated. Dashed and solid curves are for τ_p = 0 and 0.14, respectively.

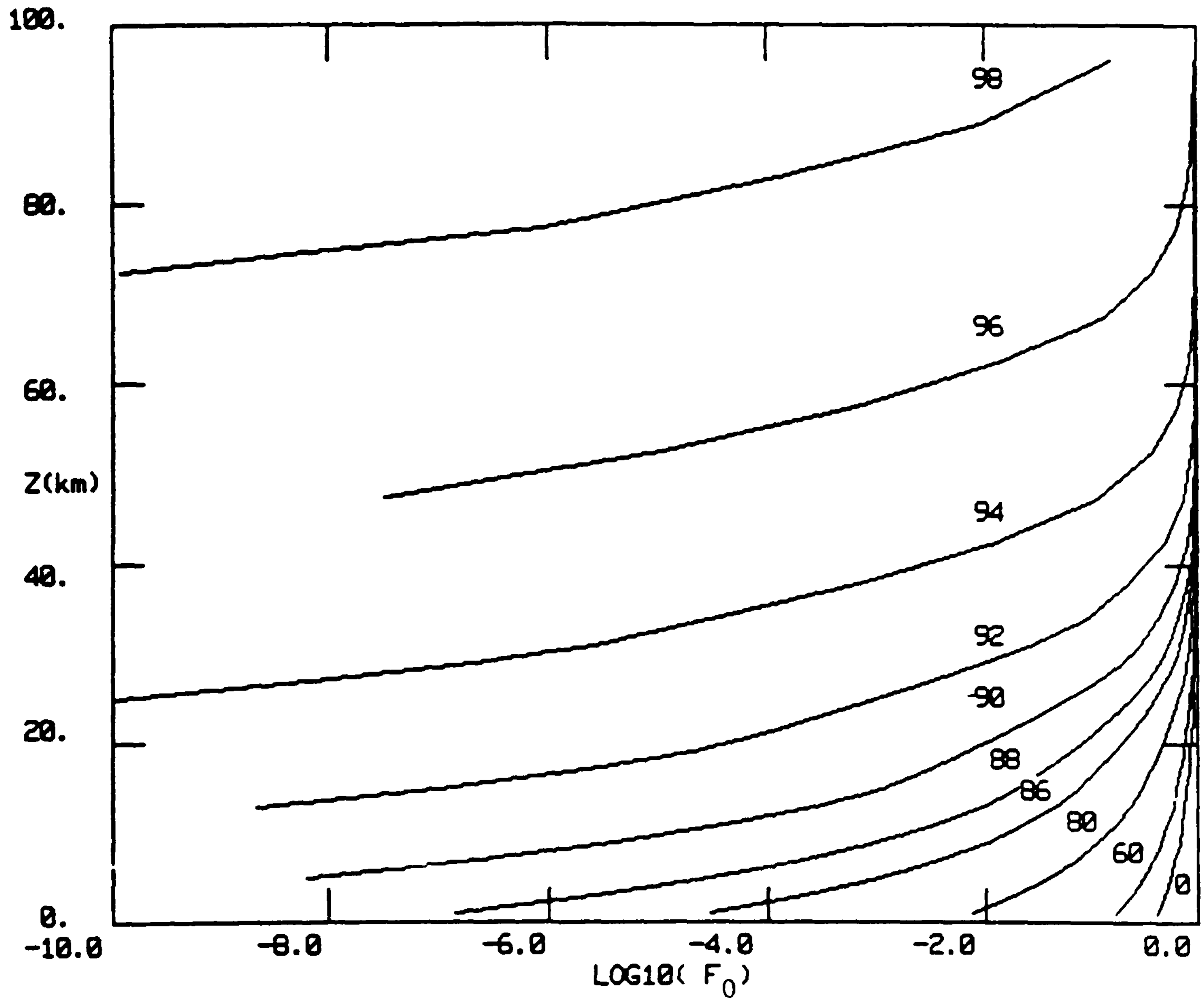


Figure 4. Spherical F_o at λ = 325 nm and, Θ_o as indicated.

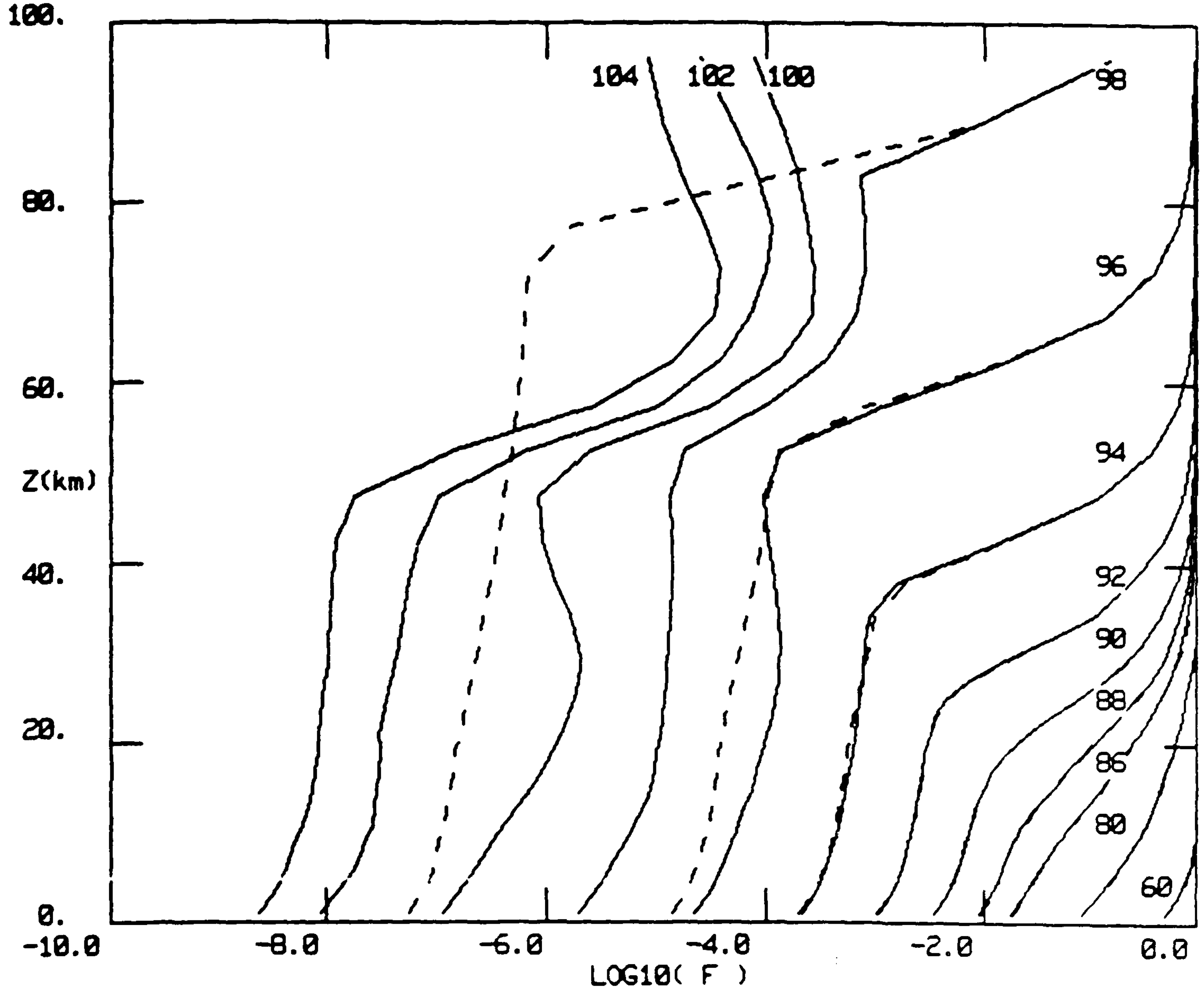


Figure 5. F as a function of θ_o at λ = 325 nm. Solid curves are spherical solutions, and dashed curves are plane parallel solutions. θ_o as indicated.

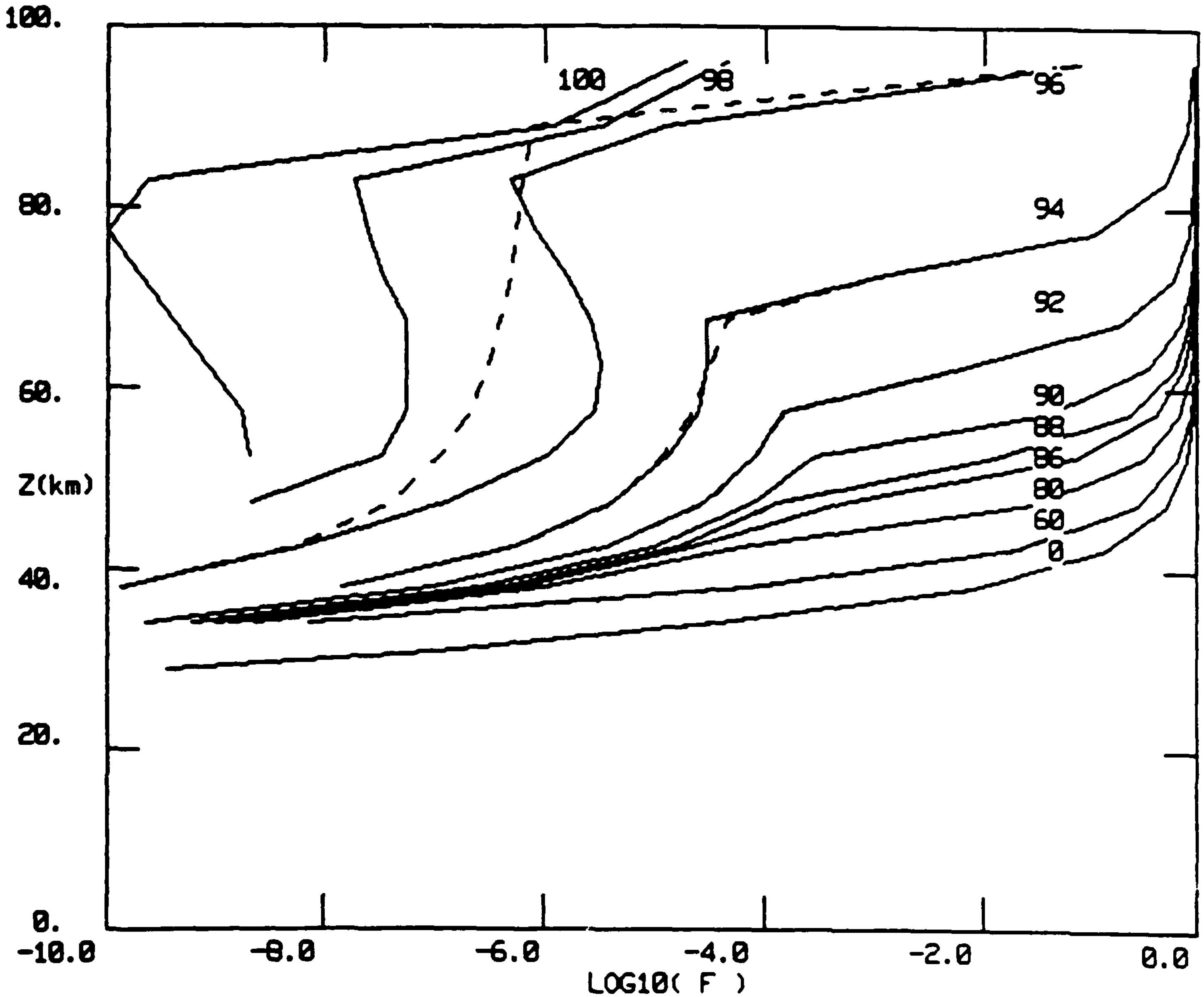


Figure 6. F as a function of Θ_o at $\lambda = 250$ nm. See Figure 5 caption.

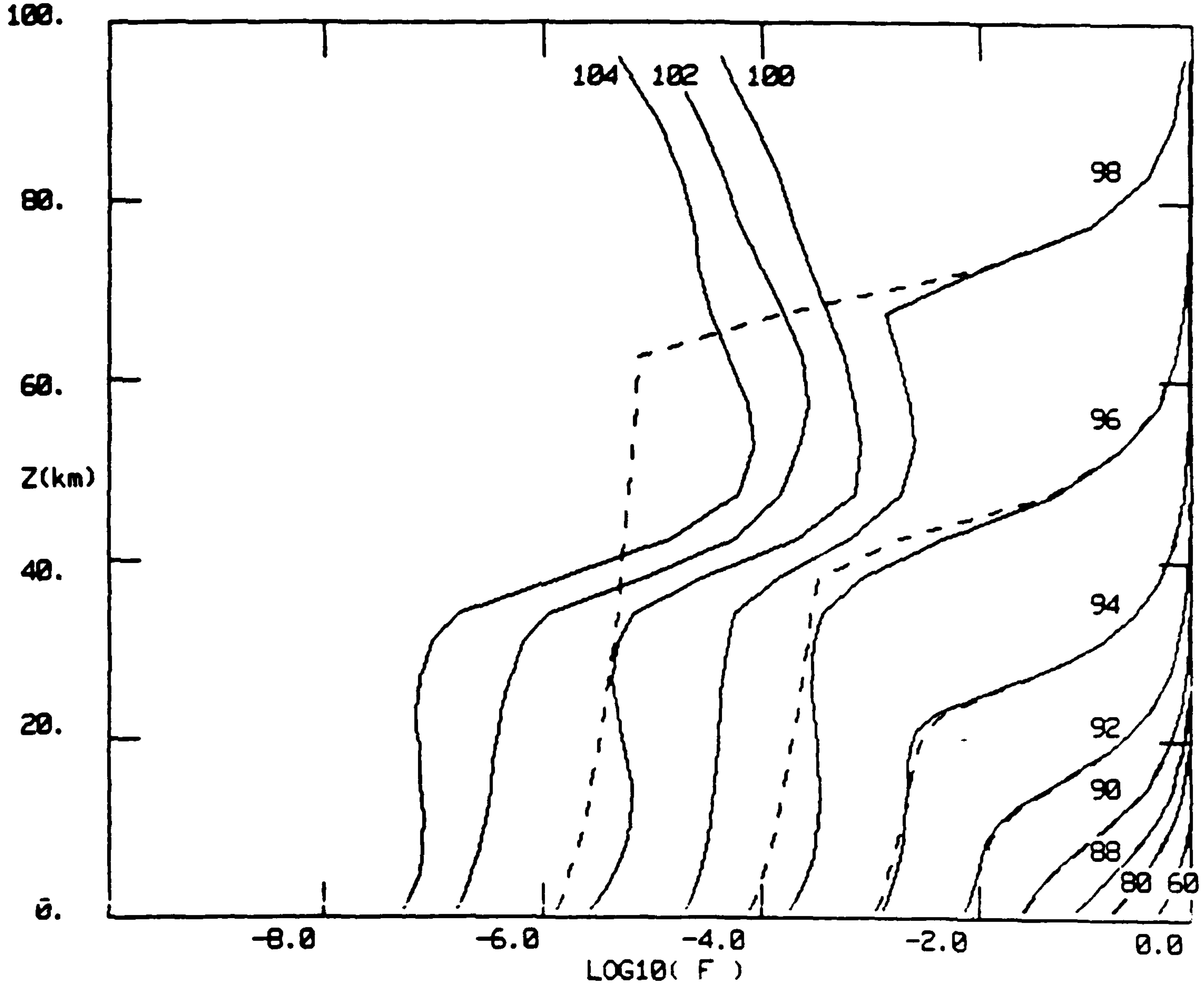


Figure 7. F as a function of O_o at λ = 450 nm. See Figure 5 caption.

ATE

LMED

83